Researching alternative, sustainable agricultural systems. A modelling approach by examples from Denmark*

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ABSTRACT: In recent decades agriculture has undergone rapid technological and structural changes. This development has raised concerns about the sustainability of modern agriculture and motivated an interest in alternative and, perhaps, more sustainable agricultural systems. Agriculture involves both ecological and social systems, and research in agricultural systems therefore faces the dual challenge of understanding complex agro-ecosystem interactions and handling the involvement of human actors, their practices and preferences. A major survey to assess the consequences of phasing out pesticide use in Denmark is presented as an example of a study confronting this dual challenge. The survey included the modelling of a total organic conversion of Danish agriculture, and this work is used to illustrate significant methodological issues in agricultural systems research. The removal of pesticides implies radical changes, and although the models implemented in the survey were based on all the available scientific knowledge, the work revealed insufficient knowledge in many areas. This, in turn, made it clear that the modelling could not be done without an inquiry into the different values involved. In particular, different conceptions of precaution and sustainability played major roles in the work.

KEYWORDS: agricultural systems, methodology, organic farming, values, sustainability, precautionary principle

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1 Introduction

In recent decades agriculture has undergone rapid technological and structural changes. This development has raised concerns about the sustainability of modern agriculture and the consequences for public health. The general problems of zoonoses and the recent events in connection with the outbreak of bovine spongiform encephalopathy (BSE) in Great Britain and other countries provide obvious examples of this. But the use of pesticides in agriculture has also been a significant concern for many years. The evident problems connected with modern agriculture raises questions concerning the deeper causes. Here, the question is what systems science can do in the investigation and solution of such systemic problems and in the sustainable development of agriculture. And conversely, what sustainability can do to systems science.

In this paper we suggest that the problems related to sustainability in agriculture pose a special challenge to systems science methodology. Agriculture involves both ecological and social systems, and research in agricultural systems therefore faces the dual challenge of understanding complex agro-ecosystem interactions and handling the involvement of human actors, their practices and preferences. When social dynamics are included in systems science, it can no longer be strictly descriptive. Agricultural systems research is inherently framed in a social context, and value inquiry is an indispensable part of any such situated systems science. This includes questions concerning different interests in society as well as different structures of rationality and meaning (Kristensen & Halberg 1997).

The problems of modern agriculture motivate an interest in investigating alternative and, perhaps, more sustainable agricultural systems. This paper is based in part on work done in connection with a major survey, which were to assess the consequences of phasing out pesticide use in Danish agriculture. The survey was initiated by the Danish Government and coordinated by the Bichel Committee, which was appointed by the Minister of Environment in 1997. The mandate for the committee stipulated that a main committee should be appointed with expert members from research, farmer associations, ”green” organisations, agricultural and food industries, trade unions and relevant ministries. In addition four subcommittees were appointed to facilitate the main committee’s final reporting by drafting specialist background reports in the areas of agricultural production, economics and employment, environment and public health, and legislation. As a later addition, an inter-disciplinary group was appointed, with representatives from each of the subcommittees, to perform an assessment of the consequences of a total organic conversion of Danish agriculture.

The successful completion of an assessment of such complexity presumes a massive effort. The proportions of the Bichel survey can be illustrated by a few statistics. Each of the five committees had 5 to 20 expert members and held 10-20 meetings over a period of 1½ years. And specialists in different fields wrote more than 60 consultant reports to the committees. The results of the assessment have been published in Danish in 1999 in five background reports and a final report from the main committee. These reports, as well as the many consultant reports, are available at the Danish

Environmental Protection Agency[1]. The final report is also available in an English translation (Danish EPA 1999a).

The Bichel survey is presented here as an example of a concrete study confronting the challenges posed by the complexity of agricultural systems, which is used to illustrate significant methodological issues in agricultural systems research. The work in the Bichel committees indicated both the abilities and the limitations of scientific knowledge and "hard" systems science in an investigation of alternative agricultural systems. The massive effort, drawing on the available expert knowledge, provided an overview of what can be said today of the consequences of phasing out pesticide use in Denmark. These results are now widely recognised and acclaimed. And based on the results, the main committee did in fact reach consensus on a range of policy proposals for the government, in spite of the very different interests represented in the committee. But the work in the committees also documented the present gaps and limits of scientific knowledge, and it became quite clear that the assessment could not be done without an inquiry into the different values involved.

Among the social values associated with agriculture, the focus here is on the concepts of precaution and sustainability. Growing awareness of the limits of scientific knowledge has led to an increasing emphasis on the concept of precaution (Vorsorge) in agricultural and environmental policy (O'Riordan & Cameron 1994; Raffensberger & Tickner 1999). The concept of sustainability is widely used in agriculture, but there appears to be a large variability in the interpretation of the meaning of sustainability (Douglass 1984; Thompson 1997). In connection with the work on a total organic conversion in the Bichel survey, different perceptions of sustainability played a particular role, because the concepts of precaution and sustainability are intimately related in the ideas and principles of organic farming (Danish EPA 1999b).

This paper will deal mainly with the work done in the Bichel Committee to assess the consequences of a total conversion to organic farming in Denmark. This work allows for a rich discussion of the interplay of science and values, because there is an established practice of organic farming, which is based on formulated values and principles, as well as existing consumer preferences for organic products and green organisations with a political preference for organic farming due to environmental concerns.

2 The methods used in the assessment of the overall consequences of phasing out pesticide use in Denmark

The Danish Minister of Environment appointed the Bichel Committee with the task of answering the following question: *What are the overall consequences of phasing out the use of pesticides in Danish agriculture?* This is an interesting question in itself, and an answer has been given (Danish EPA 1999a). In section 3 the results with regard to a

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total organic conversion are presented, but in this section the focus is on the modelling involved and the methodological questions emerging in such a task. The methodological questions are broken down into general questions concerning the presumptions that are necessary to begin the modelling involved and more specific questions involved in the actual modelling of scenarios.

2.1 The general methodology

The first methodological task in answering a question like "what are the consequences of …?" is to establish the system in question and specify the end point or scenario and the point of reference, which "the consequences of" refer to. The mandate of the Bichel Committee established that the system in question was the Danish agricultural system. The end point was specified in terms of different scenarios for the total and partial phasing out the use of pesticides, and (as a later addition) a total conversion to organic farming. And the assessment was to include both the consequences to the Danish society and to the environment. As stated in the introduction, this paper deals mainly with the total conversion to organic farming. Still, there are many open questions to be discussed and determined in order to answer the question of "what are the consequences", even given the delimitation to organic conversion.

The end point: the all-organic scenario

What will an all-organic Danish agriculture look like? An answer (or more answers) to this question is needed in order to assess the consequences of a total conversion. Organic farming aims at establishing stable and harmonic systems, which integrate livestock and crop production. As an example, the associations for organic and biodynamic farming in Scandinavia have endorsed the following description of organic farming:

> Organic farming means a self-sufficient and sustainable agro-ecosystem in a balanced state. The system is based as far as possible on local, renewable resources. Organic farming builds on an integrated ethos, which encompasses the environmental, economic and social aspects of agricultural production in a local as well as in a global perspective. Thus, in organic farming nature is considered as an entity with value in itself, and human beings have a moral responsibility for farming in a manner which makes the cultivated landscape a positive part of nature.
>
> (Ministry of Food, Agriculture and Fisheries 1999)

In accordance with the present practice and rules of organic farming, no industrially manufactured fertilisers, pesticides or growth regulators are used. The nutrient management is based on the use of animal manure, green manure, and crop residues and on nitrogen fixation by legumes. Weeds, pests and diseases are controlled through the use of versatile crop rotations, mechanical weed control and a proper choice of varieties.

However, organic farming constitutes only a minor part of agriculture today and there is no predetermined or unequivocal vision of how an all-organic Danish agriculture would look like. Therefore it was decided in the Bichel Committee to work with a range of different scenarios, with the intention of extending a possibility space for a future all-organic agriculture. The space was stretched out by means of three different presumptions on the level of import of feed to Denmark, with ensuing differences in the level of nutrients in circulation and subsequent consequences for production, environment and economy:

a) No import of feed to Denmark
b) Restricted import of feed at the same level as today's rules for input of conventional fodder (app. 10% of dry matter for ruminants and 20% for monogastrics)
c) Unlimited import of feed and maintaining the present Danish production of animal products

The chosen scenarios can be characterised as consistent calculations based on the present practice and available knowledge of agriculture today. Apart from this, the scenarios are constructed on a range of presumptions that determine the scenarios as "all-organic scenarios" in accordance with the present rules of organic farming. The scenarios mainly represent the restrictions in an all-organic agriculture that are the consequences of a fall in the size of the production. It is not possible to represent the future possibilities (e.g. in terms of production, manufacturing and marketing) in an all-organic agriculture to the same extent, because these possibilities are, for a large part, dependent on innovation. And innovation can by definition not be determined in advance. However, some foreseeable possibilities for a higher production level that are based on existing knowledge, such as a higher focus on organic grain production and higher yields in grass-clover due to lover milk yields per cow, have been included in form of two crop yield levels:

1) Present yield level based on existing data on organic farming
2) Improved yield level including foreseeable beneficiary consequences for the primary production in an all-organic agriculture

The point of reference: agriculture today

Apart from the questions concerning the end point or scenario, there is the question of the point of reference with which to compare the scenario. In general there are two possibilities, making a reference scenario or choosing a historic point of reference. Danish agriculture in general is in rapid development in many respects. Technological changes, shifts in productions and types products, and changes in regulations are taking place continuously. A spurious point is that conversion to organic farming is one important type of change in Danish agriculture, since the land area with organic farming has risen from 0,2% in 1988 to 6.5% in 2000.

The most important consideration concerning the point of reference is that it should be consistent and representative of the real system. These considerations talk in favour of a historic point of reference. On the other hand there is an obvious desire to take account of the changes that have already taken place after this historic point of reference, and of the foreseeable future changes. Including such changes does, however, presume that a comprehensive and consistent scenario has been worked out, which includes all the relevant consequences of the change in question.

In the Bichel Committee Danish agriculture in the crop year 1995/96 was chosen as a historic point of reference, in order to have consistent reference data with which to compare. In terms of crop production levels a longer reference period was chosen (1993-1996), in order to take account of yearly variations. One available comprehensive and consistent scenario for a future Danish agriculture (VMP 2) was incorporated as point of reference in the nutrient balances. This scenario was elaborated as part of a governmental plan for protection of the aquatic environment.

The consequences
A further methodological choice is connected with the question of which consequences are to be evaluated. The major types of consequences (consequences for the agricultural production; for manufacturing, economy and employment; and for environment and health) were given in the mandate to the committee. Furthermore it was presumed that only the Danish consequences were relevant. But the more specific determination of relevant consequences were left to the work of the committee, and some of the choices made there can be gathered from the presentation of the results in section 3.

2.2 The modelling of an all-organic agriculture

Figure 1 shows the overall structure of the material flows in a simple model of an all-organic agriculture. The model consists of two parts, crops and livestock, which are interdependent. The crop part receives a nutrient input (organic waste, atmospheric deposition, etc.) from outside the model and produces crop products (cereals, potatoes, vegetables, fruits, etc.). The livestock part receives a feed input (feed import, surpluses from manufacturing, etc.) from outside the model and produces animal products (milk, pork, beef and eggs). Within the model, the crop part produces the major part of the feed input to livestock, which in turn produces the major part of the manure input to the crop part.

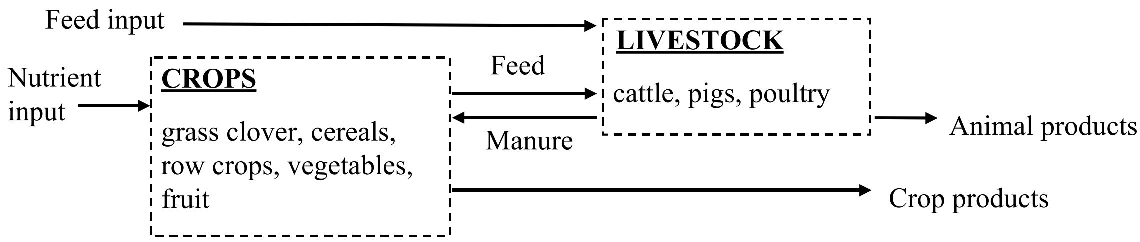

Figure 1: Overall structure of the material flows in a model of an all-organic agriculture in Denmark.

The model that was used for calculating the size of the agricultural production in the organic scenarios is illustrated in more detail in figure 2. The figure includes the most important variables and relations in the model. The rectangular boxes indicate empirical variables that are not dependent on the model presumptions, the rhomboid boxes indicate decision variables which determine the model input from empirical data and model presumptions, and the rounded boxes indicate model variables that are independent of the presumptions, given decision variables and model structure. The input and output variables from figure 1 are grey.

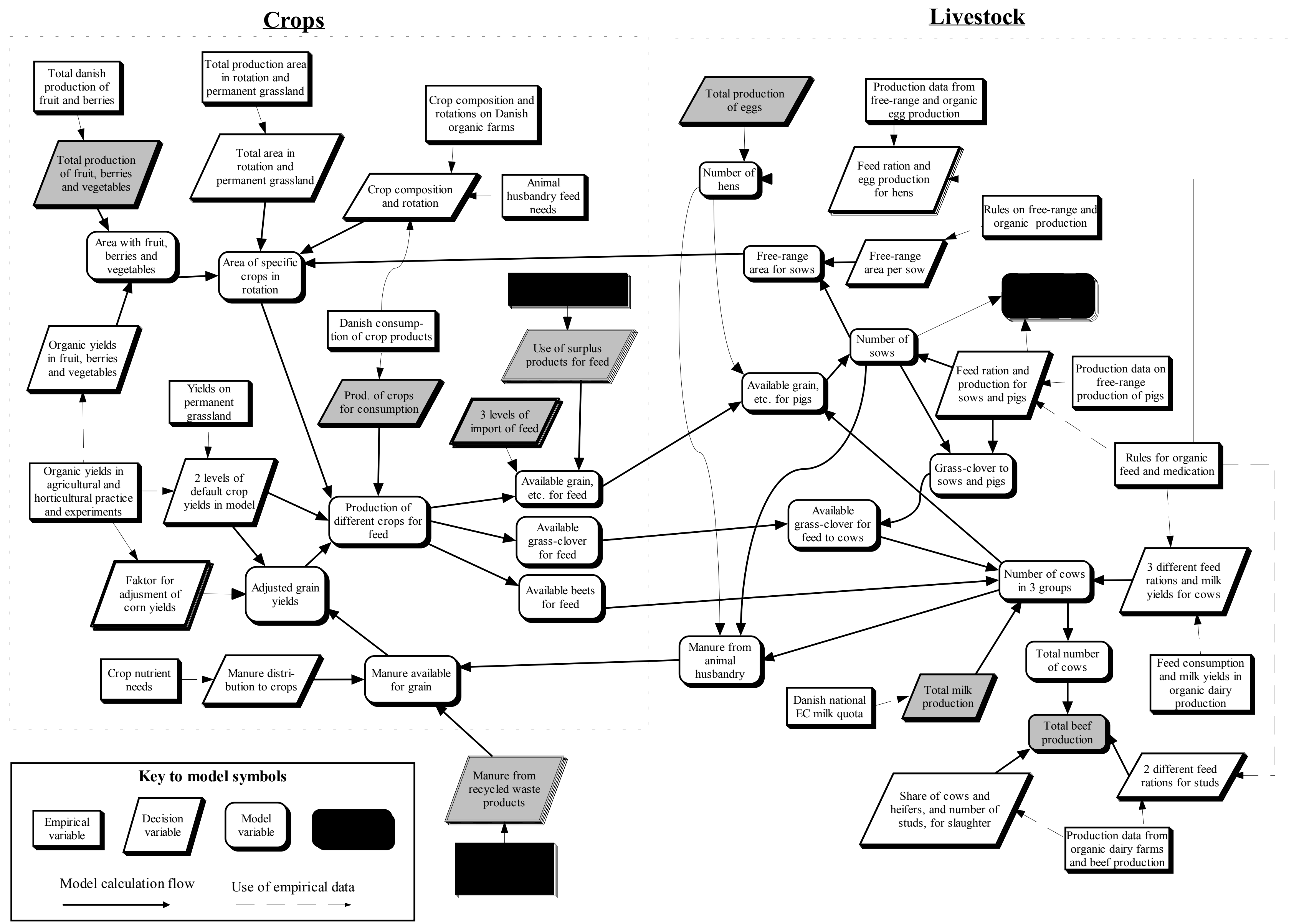

Figure 2: The model for calculation of the organic scenarios.

Not shown in figure 2 are the details involved in determining the yield and production levels and the connected feed consumption and production systems, based on the available empirical knowledge from practice and experiments (Alrøe *et al.* 1998b; Hermansen *et al.* 1998). Also not shown in figure 2 are the further modelling and calculations, which were based on this basic model of an all-organic agriculture, such as the calculations of nutrient and energy balances, loss of nutrients, emission of greenhouse gases and use of pharmaceuticals. This model for the organic scenarios involves a range of preconditions and presumptions, which are described below.

General preconditions and presumptions for the model structure
The first general preconditions for the model is the total area of agricultural production in Denmark today (2.7 mill. ha). This area, which includes areas with permanent grass, fruits and berries as well as set-aside land, is taken as the total area in the organic scenarios. Areas with ornamentals and greenhouse production are excluded from the model. The production of fur animals is also excluded. A further important precondition is that the agricultural products and vegetables that are normally produced and consumed in Denmark are to be included in the model. And furthermore, that they are to be produced at certain minimum levels, which correspond to the Danish national consumption. For simplicity only the major types of animal products are modelled: milk, beef, pork and eggs (poultry meat is modelled as pork).

Another general precondition is the present Danish national EC quota on milk. The national quota determines the production of milk in the model. This, in second hand, to some degree determines the production of beef, because the number of dairy cows and their production of offspring restrict the beef production. Given the national quota, the number of dairy cows is determined by the milk yield per cow, which in turn is dependent upon the available feed (mainly grass-clover) and the feed composition for the cows. Three different types of feed rations are incorporated in the model, in order to allow for the different production strategies found in Danish dairy farming today. The production of eggs is determined by the present production in Denmark, which largely corresponds to the national consumption. The production of pork and poultry varies with the available amount of nationally produced feed, including the restricted import of feed in scenarios where this applies. In the scenarios with unlimited feed import these calculations are reversed and the necessary import is determined by the present production of pork and poultry (Alrøe *et al.* 1998a).

Further necessary preconditions for the model are the crop composition, the determination of crop production levels and amounts of by-products (e.g. straw), which is elaborated below, and determination of feed consumption and animal production levels.

Crop composition and rotation
Another set of presumptions and preconditions are connected with the crop composition and the production levels in the organic cropping systems. The fundamental basis for a stable organic cropping system is a versatile and harmonic crop rotation, with a suitable share of perennial and nitrogen fixing crops. This imposes limits to the specialisation of crop production, and it is for instance not possible to make an organic cropping system with only annual crops like in conventional agriculture. Furthermore the crop

composition and the choice of varieties has to be to be suitable for the local climatic and edaphic conditions.

Due to the local adaptation and the general complexity of organic farming systems, the crop composition in an all-organic scenario has to be based on the empirical evidence from existing organic farms in Denmark. The Danish Institute of Agricultural Sciences has performed comprehensive studies of both organic and conventional dairy farms since 1988 (Kristensen & Sørensen 1991; Kristensen & Halberg 1995; Halberg & Kristensen 1997). Since 1994 the studies have included organic arable farms and farms with egg production (Kristensen 1996; Kristensen 1997). Organic pig farms have only very recently been established in Denmark, while free range pig farms have been included in the studies since 1996 (Hermansen 1998; Larsen *et al.* 1999).

The above studies indicate that a suitable crop rotation for organic farming in Denmark is a five year rotation with the following composition:

1. year: spring cereal
2. year: grass-clover
3. year: grass-clover
4. year: cereal
5. year: cereal/row crop

This crop rotation is taken as the basis for the all-organic model as a national average on the agricultural area in rotation (excluding permanent grassland and areas with fruits and berries). This does not imply that all farms in practice would have this rotation, nor that the average rotation would be the same in all parts of the country. On better soils for cereal production (clayey soils) one or more years of cereal or row crop production may be added and on poorer soils (sandy soils) one year of cereal or row crop production may be deleted.

An important consequence of taking the above crop rotation is a basis for all organic farming is that the share of grass-clover in the agricultural production area is 40%. This precondition is maintained through out the modelling process in recognition of the need to pay due respect to the agricultural limitations in organic production. Accordingly, the correspondence between the production of grass-clover for feed and the production of milk is secured by way of calculating the appropriate number of cows on different feed rations and not by changing the share of grass-clover in the crop rotation.

Production levels

The empirical basis for assessing the production levels in an all-organic agriculture consists in data from different types of studies and experiments. The Bichel survey included data from farm studies, long term experiments on farming systems and cropping systems, on-farm experiments, and farm accounts. An analysis of the context and characteristics of the different types of data was performed in order to give the best possible estimates for the expected production levels. The analysis showed that the farm studies provided the best basis for the estimates, and that they were in agreement with the data from farm accounts when adjusted for yearly variations. The data from long term experiments were more precise and the context of the data was better described, but the data were not representative of production on private farms due to near optimal management and the limited number of trials (Alrøe *et al*. 1998b).

The overall production of crops in an all-organic agriculture is dependent on the amount of nutrients available to the crops. This amount, in turn, is influenced the agricultural practice as well as the amount of nutrients in circulation through livestock and humans. The available sources for recirculation of nutrients from society in form of organic waste were calculated in the analysis, but this potential were not included in the model due to the present uncertainty of the technological feasibility and consequences for health and environment. Hence, the available amount of manure in the different organic scenarios varies in correspondence with the number of livestock, which in turn is dependent on the production and import of feed. The production levels in the model are adjusted for the available amount of manure in an iterative operation, in accordance with empirical data (Askegaard & Eriksen 1997, Danish EPA 1999b:25).

Economy
The all-organic scenarios describe a situation 30 years into the future, because a total organic conversion involves very large structural changes in Danish agriculture. These structural changes are due to a presumption that the animal manure is distributed evenly in proportion to the crops needs, which in turn involves an even distribution of livestock, and to changes in farm production and housing systems. The 30 year horizon allows for a total organic conversion without substantial excess costs in connection with the scrapping of production systems.

Further assumptions, which are important in the calculation of economic consequences, are that the total organic conversion only takes place in Denmark; that the analysis is based on a "compulsory" conversion, which means that any Danish consumer preferences have not been valued. However, a sensitivity analysis has been performed on consumer preferences for organic products on the export markets.

3 The consequences of a total conversion to organic farming in Denmark

The all-organic scenarios describe the expected agricultural production based on the preconditions and presumptions outlined in the previous section, and the available empirical knowledge. Six different scenarios were calculated, based on three levels of feed import to Denmark and two yield levels in grain and grass-clover. The connection between the chosen model presumptions and their consequences are discussed in section 4. A summary of the results of the model is given below. First the consequences of a total conversion for the agricultural production as such, and next the connected consequences for the environment and society.

Consequences for the agricultural production
As shown in table 1, the production of grain in the scenarios is significantly lower than in the present Danish agriculture, while the production of roughage (mainly grass-clover in the model) is higher. This is due to a different crop composition in combination with lower yields. Production of Alfalfa is included in the scenarios without feed import, due to livestock feed needs, despite the very limited organic production of alfalfa today.

Table 1: Total production of agricultural products in Denmark, 1996, and in the organic scenarios (Alrøe et al. 1998a; Danish EPA 1999a:109)

	Danish agriculture 1996	*Organic scenarios*					
		Present yield level			*Improved yield level*		
		No import	*Restricted*	*Unlimited*	*No import*	*Restricted*	*Unlimited*
Grain (*mill. FU*)[a]	9,850	3,678	4,549	4,785	4,581	5,448	5,506
Grass etc. (*mill. FU*)	3,269	5,311	5,165	5,060	5,721	5,525	5,495
Fodder beets (*mill. FU*)	440	537	537	537	440	537	537
Rape (*mill. kg*)	251	271	0	0	247	0	0
Grass seed (*mill. kg*)	64	13	13	13	13	13	13
Potatoes (*mill. kg*)[b]	1,617	327	327	327	327	327	327
Sugar (*mill. kg*)[c]	493	225	225	225	225	225	225
Vegetables (*mill. kg*)	291	291	291	291	291	291	291
Fruit and berries (*mill. kg*)	61	61	61	61	61	61	61
Milk (*mill. kg)*	4,690	4,650	4,650	4,650	4,650	4,650	4,650
Beef (*mill. kg*)	198	202	195	190	207	199	197
Pork and poultry (*mill. kg*)	1,773	531	1,255	1,773	793	1,645	1,773
Eggs (*mill. kg*)	88	88	88	88	88	88	88

FU: International feed units

[a] Grain for feed, seed and human consumption, including pulses.

[b] Potatoes including laying potatoes (and, for Danish agriculture 1996, potatoes for industry)

[c] Reffined sugar

Table 2: Danish feed import and export of agricultural products in 1996 and in the organic scenarios (Alrøe et al. 1998a; Danish EPA 1999a:110)

	Danish agriculture 1996[a]	*Organic scenarios*					
		Present yield level			*Improved yield level*		
		No import	*Restricted*	*Unlimited*	*No import*	*Restricted*	*Unlimited*
Feed import (mill FU)[b]	*3,513*	*0*	*2,300*	*4,158*	*0*	*2,715*	*3,176*
Grain (*mill. kg*)	2,022	0	0	0	0	0	0
Rape (*mill. kg*)	58	0	0	0	0	0	0
Grass seed (*mill. kg*)	61	0	0	0	0	0	0
Potatoes (*mill. kg*)	421[c]	0	0	0	0	0	0
Sugar (*mill. kg*)	160	0	0	0	0	0	0
Milk (*mill. kg*)	2,352	2,312	2,312	2,312	2,312	2,312	2,312
Beef (*mill. kg*)[d]	96	100	93	88	105	97	95
Pork and poultry (*mill. kg*)[e]	1,342	100	824	1,342	362	1,214	1,342
Eggs (*mill. kg*)[f]	6	6	6	6	6	6	6

[a] The figures for export of crop products in 1996 are only to be taken as indicative, since there are large yearly variations.

[b] Grain constitutes app. 10% af the feed import in 1996, but more than 50% of the feed import in the organic scenarios.

[c] Including the share exported as potato flour.

[d] Calculated as production i slaughtered weight minus national consumption (102 mill. kg); exclusive the export of 54,500 heads of cattle in 1996, corresponding to 3 mill. kg live weight.

[e] Calculated as production i slaughtered weight minus national consumption (431 mill. kg); exclusive the export of 692,000 heads of pigs in 1996, corresponding to 33 mill. kg live weight.

[f] Calculated as production minus laying eggs (10 mill. kg) and national consumption (72 mill. kg)

The production of crops for seed and human consumption is determined by the presumptions in the model. However, the analyses showed that the organic production of some high-value crops, fruits and a few vegetables was very problematic. In today's agriculture these crops are sprayed more than other crops and the economic value of the pesticide treatment is high. In apples a massive reduction in yields can be expected, if the present varieties are used.

The model results show that the production of milk, eggs and beef can be maintained in all the organic scenarios. The differences in grain production and feed import in the different scenarios are mainly reflected in the production of pork and poultry, due to the presumptions in the model (see section 2.2). The feed import is shown in table 2, together with the export of agricultural products. The pork and poultry production necessary for national consumption can be fulfilled in all the scenarios, while the export falls 10-40% in scenarios with restricted feed import and 70-90% in scenarios with no feed import.

Nutrient balances, the environment and public health
As indicated above, the basic technological restrictions in an over-all organic agriculture, especially the restrictions on pesticides, artificial fertilisers, and growth promoters, result in a somewhat different and substantially lower agricultural production. But these agricultural restrictions also involve benefits to environment and society.

The circulation of nutrients is substantially lower in the organic scenarios due to the removal of the input of artificial fertilisers. For instance, the calculated net supply of nitrogen to the soil was reduced to 30-50% of the 1996 level – a level corresponding to the circulation in Danish agriculture in the 1950's (table 3). In the long term this reduction implies a substantially reduced potential for nitrogen leaching, which is a major environmental concern in Denmark.

The supply of nitrogen to the crops is secured mainly through fixation and recirculation of manure in the organic scenarios. But for the other nutrients there may be a problem with deficits on the balances. These nutrients are mainly removed with the output of agricultural products and through leaching. A long term sustainable agriculture must maintain the fertility of the soil, and generally this involves keeping a balance between input and output of nutrients. The calculations in the organic scenarios showed a balance for phosphorous because the input of minerals for feed roughly corresponded to the output in products, and the leaching of phosphorous is very limited. But the analysis showed a deficit on the potassium balance, because potassium can leach in substantial amounts in the more sandy soils in Denmark.

The consumption of fossil energy and the emission of greenhouse gases would fall with the size of the livestock production in the organic scenarios (table 4). Furthermore, energy consumption per produced unit would be lower in both plant and livestock production, mainly due to the changes in crop composition and the removal of the input of industrially synthesised nitrogen fertiliser. On the other hand the potential for using more agricultural products as sources of energy would be reduced.

Table 3: Nitrogen balances in 1996, after the implementation of the plan for the aquatic environment (VMP 2), and in the organic scenarios (mill. kg per year) (Grant 1998; Danish EPA 1999b:37)

	Danish agriculture 1995/96	*VMP 2*	*Organic scenarios*					
			Present yield level			*Improved yield level*		
			No import	*Restricted*	*Unlimited*	*No import*	*Restricted*	*Unlimited*
Feed , etc.	205	179	6	94	148	18	109	122
Art. fertilizer	285	177	0	0	0	0	0	0
Sludge, waste	9	9	0	0	0	0	0	0
Atm. deposition[a]	57	57	57	57	57	57	57	57
Fixation	30	31	159[b]	159[b]	159[b]	177[b]	177[b]	177[b]
N input	*586*	*452*	*222*	*310*	*364*	*253*	*343*	*357*
Crop products	63	42	19	19	19	19	19	19
Animal products	105	105	58	82	100	66	96	100
N output	*168*	*147*	*76*	*100*	*118*	*85*	*114*	*119*
N balance	*418*	*305*	*146*	*209*	*245*	*167*	*229*	*238*
Ammonia loss[c]	76	69	45	57	67	50	65	67
N to the soil, net	*342*	*236*	*101*	*152*	*178*	*117*	*164*	*171*

[a] The same atmospheric deposition is used in all scenarios, not incorporating the consequences of the changes in ammonia loss following from the changes in livestock.

[b] An estimate for the uncertainty on the size of the fixation in the organic scenarios has been calculated to 56 mill. kg.

[c] The calculation is based on etimates for N ab anima, estimates for ammonia loss and denitritficaiton in housings and stocks, in the delivery of manure, and in grazing. These losses are dependent on the production system. Furthermore there is a loss of ammonia from crops (11 mill. kg). In 1995/96 and the VMP 2 scenario there is furthermore a loss from artificial fertilizer (7 mill. kg) and from the ammonia treatment of straw (4 mill. kg).

Table 4: Consumption of fossil energy in Danish agriculture and the organic scenarios compared with crop and animal production (Dalgaard *et al.* 1998, Danish EPA 1999b:51).

	Danish agriculture 1996	*Organic scenarios*					
		Present yield level			*Improved yield level*		
		No import	*Restricted*	*Unlimited*	*No import*	*Restricted*	*Unlimited*
Crop product. (*mill. FU*)	15,900	11,000	11,400	11,600	12,300	12,800	12,900
Crop product. (*PJ ME*)[a]	199	138	143	145	154	160	161
Number of animals (*mill. Livestock Units*)	2.3	1.7	2.1	2.4	1.9	2.3	2.4
Energy for crop production (*PJ*)	37	17	17	17	17	17	17
Energy for animal production (*PJ*)	41	13	29	41	14	31	37
Total energy consumption (*PJ*)	78	30	46	58	31	49	54
Energy production (*PJ*)	14[b]	0	0	0	0	0	0
Net consumption (*PJ*)	64	30	46	58	31	49	54

[a] Converted from feed units to metabolic energy (1 FU = 12,5 MJ ME).

[b] There is a potential for further energy production in the present agriculture, corresponding to the grain that was exported in 1996 (2000 mill. kg * 15 MJ/kg = 30 PJ). The use of this potential will have other socioeconomic consequences.

The total conversion to organic farming would involve a substantial increase in the amount of flora and fauna on the rotation area (Danish EPA 1999a:114). The species diversity would increase on a longer term, but mainly with species that are fairly common. The largest qualitative consequences of the conversion would be found in the semi-natural areas and in the small uncultivated biotopes, such as water holes, hedges and dikes, due to the stop for intended and unintended spreading of pesticides and artificial fertilisers. However, a very large "ecological inertia" must be expected after damages of the natural content in these areas, because of the retainment of nutrients and slow re-colonisation.

The consequences for public health of a total conversion to organic farming would depend on changes in the intake of physiologically active substances, which in turn depends on changes in food products as well as changes in the intake of different food products. A number of changes can be expected in the content of physiologically active substances in the food, but these changes would generally be small compared to the effect of changes in the composition of the diet. The Bichel Committee concluded that it cannot be proved on the basis of existing epidemiological studies that pesticides are harmful to health in the quantities to which the general population is exposed to them (Danish EPA 1999a:25).

The analysis shows that the use of therapeutic pharmaceuticals would fall approximately 30% in the organic scenarios with maintained livestock production (Danish EPA 1999a:115). The use of antibiotic growth promoters would end altogether, which is presumed to reduce the risk of transference of resistance to bacteria pathogenic to humans. However, antibiotic growth promoters are being phased out in conventional farming as well.

Economy and law

It is extremely difficult to predict the socio-economic consequences of a total conversion to organic farming, because the changes in the agricultural sector are so radical, and due to the number of associated sectors that are more or less influenced. However, a calculation of the socio-economic costs has been performed on the four scenarios with restricted and no feed import, based on the presumptions described in section 2.2 (Danish EPA 1999a:145; 1999b:69-70). The socio-economic costs of a total conversion were calculated to a 1.2-3% reduction of the Danish gross national product. The fall in Danish private consumption, which can be taken as a measure of the economic welfare consequences, were from 9-24 billion DKK (1.2-3.3 billion Euro) per year. In a sensitivity analysis made for one scenario, consumer preferences for organic products on the export market were presumed to correspond to a price premium of 10% on milk and 20% on pork. In this case, the fall in private consumption was reduced from 9 to 3 billion DKK.

The socio-economic benefits of organic conversion are even more difficult to calculate. However, a calculation has been performed of the value of quantifiable environmental benefits from phasing out pesticide use, reduced nitrogen leaching and reduced emissions of greenhouse gases. The analysis estimates the environmental benefits to 1-1.5 billion DKK per year. This valuation is based solely on the alternative costs for society in form of savings connected to the conversion, in relation to reduced energy consumption, savings in the supply of drinking water, and an estimate of the possible savings in form of reduced leaching of nitrogen. The consequences for more "soft" values, such as quality of nature, biological diversity, and animal welfare, have not been suitable to a valuation of alternative costs. And an evaluation based on different group's or individual's "willingness to pay" for the consequences of a total conversion to organic agriculture has not been performed, nor have any usable estimates been found in the literature (Danish EPA 1999b:71-2).

The legal analysis indicates that, with respect to the present EC rules, a forced conversion to organic farming is hardly feasible. It is not possible to prohibit the import of neither conventional nor organic food and feedstuffs. A total conversion would thus only be feasible if the agricultural industries were to undertake it on their own initiative, and thus achieve a marketing advantage (Danish EPA 1999a:146). If the rate of conversion is left to consumer demand and price mechanisms, there is no guarantee for the share of conversion, but the conversion that does take place can be assumed to improve society's welfare. A market-driven conversion will, according to current economic theory, involve a more effective resource allocation in society. And the consumers will individually assign the "right" value to organic food products, corresponding to their willingness to pay. However, the conversion need not be based on market forces alone in order to improve society's welfare. Since the conversion is associated with common goods and benefits to society, apart from individual consumer decisions, society can benefit from promoting organic farming through agricultural regulation as well.

4 Discussion

In this section the methodological issues and the results of the Bichel survey will be discussed with reference to the interplay of science and values.

4.1 Methodological issues

The first methodological task in answering a question like "what are the consequences of phasing out pesticides?" is to establish the system in question, and specify the end point (the envisaged future state) and the point of reference, which "the consequences of" refer to. The envisaged future state is based on certain values - the reason we are interested in the question is that it refers to a future state, which is desirable from some point of view. Hence, an assessment like the one performed by the Bichel Committee involves two major interrelated activities: the modelling process and the value inquiry.

This is illustrated in figure 3. Modelling a future state necessarily involves certain presumptions concerning this state. In turn, the model results in a scenario, which can form the basis for a critical evaluation of the presumptions in relation to the vision of the future state and the values involved in this vision. Another important element in the modelling approach was the consultation with a range of experts in different fields and sciences, in order to critically review the generalisations of the available empirical knowledge in the models.

Assessing the consequences of phasing out pesticides involves both an assessment of the effects of pesticides on society and the environment in the present agriculture, and an assessment of other effects of phasing out pesticides as a result of changes in the agricultural system. In both cases the Bichel Committee pointed to the importance of uncertainties and lack of knowledge.

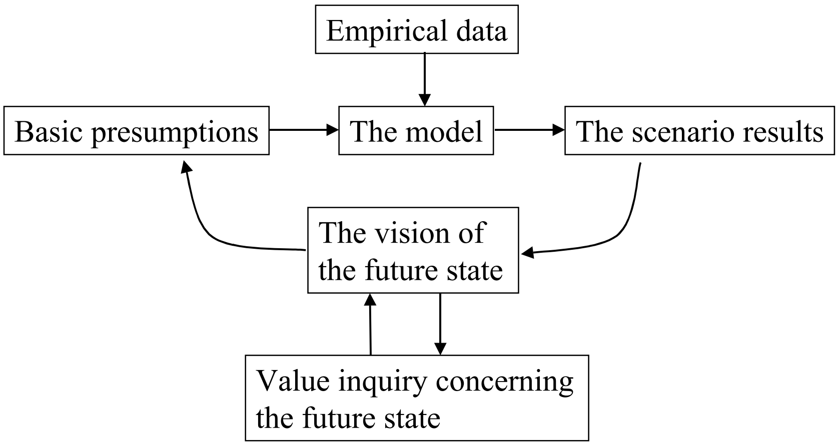

Figure 3: The relation between the modelling process and the value inquiry in an assessment like the one performed by the Bichel Committee

The major questions concerning the choice of scenarios
The system in question was given in the Bichel survey, but the scenario with which to compare the present Danish agriculture was not determined beyond the "phasing out of pesticides". One possible scenario would simply entail the present agriculture with all pesticide use removed. Obviously this is not a coherent scenario, since the removal of pesticides would have additional consequences for the agricultural practice. For instance, the farmers would change their choice of crops and crop rotations because some crops are more difficult to grow without pesticides than others are, and because crop rotations are important means to prevent pest problems. And alternative practices would be implemented, such as mechanical weed control instead of herbicides. From such considerations the Bichel Committee developed an agronomic model and calculated an agronomically optimal scenario.

However, the agronomic scenario rests on a rather slight empirical foundation. In particular, there is no established practice of conventional farming without pesticides. And in practical agriculture economic considerations are just as important as agronomic considerations. In order to better model how the farmers would actually adapt their production to the removal of pesticides, a business economical model had to be developed. And an economic optimisation was calculated, based on the agronomic model, the business economic consequences of the agronomic changes, and the economic decisions of the farmers. The business economic optimisation resulted in a very different scenario of a Danish agriculture without pesticides. Based on this scenario, the consequences for society and the environment were investigated. Still, the agronomically and business economically optimised scenario of the consequences of phasing out pesticides from conventional agriculture is heavily dependent on the presumptions regarding the farmers behaviour.

Furthermore, a modified conventional agriculture is not the only possible vision that fulfils the condition of "phasing out pesticides". The idea of an all-organic Danish agriculture constitutes a quite different vision of "phasing out pesticides". This vision entails much more than the removal of pesticides, and therefore adds to the changes in agriculture that has to be taken into account. On the other hand, the all-organic scenario can lean on the foundation of an established organic practice, which entails all the connected consequences of dispensing with pesticides in agriculture. Therefore the organic scenarios do not involve "optimisations" of the farmers agricultural practice and economical behaviour.

The work connected to the organic scenarios in the Bichel survey has been described in the previous sections, and this work will inform the further discussion of methodological issues here. The results in section 3 are considered the best available answer to the question: "what are the consequences of a total organic conversion of Danish agriculture. The answer is based on a coherent model, which rests on an established practice. Even so, the empirical basis for some of the yield and production levels in the model is rather slight. On the other hand, the model presumptions and the results have been scrutinised by the expert members of the Bichel committees.

Even given the choice of phasing out pesticides by way of a total conversion to organic agriculture, a range of presumptions was needed to establish the organic scenarios. These presumptions relate to the agronomic possibilities and limitations as well as to the ideas and values involved in the vision of an all-organic agriculture. These presumptions are discussed below in relation to the principles of organic farming, and in relation to the normative concepts of sustainability and precaution.

Principles and preferences
The model results of a total organic conversion will depend on the specific presumptions implemented, which again depend on the vision of an all-organic agriculture, as shown in figure 3. The presumptions can be considered in relation to three elements in the development of organic agriculture: practice, preferences, and rules, which all relate to the basic organic principles and values as well as to conventional agricultural practice, as illustrated in figure 4.

Organic farming originated as part of an organic movement which encompassed both consumers and producers in close relationships. The organic movement differentiated itself from conventional agriculture by way of formulating a common foundation of principles and goals, which was based on a perception of humans and human society as an integrated part of nature.

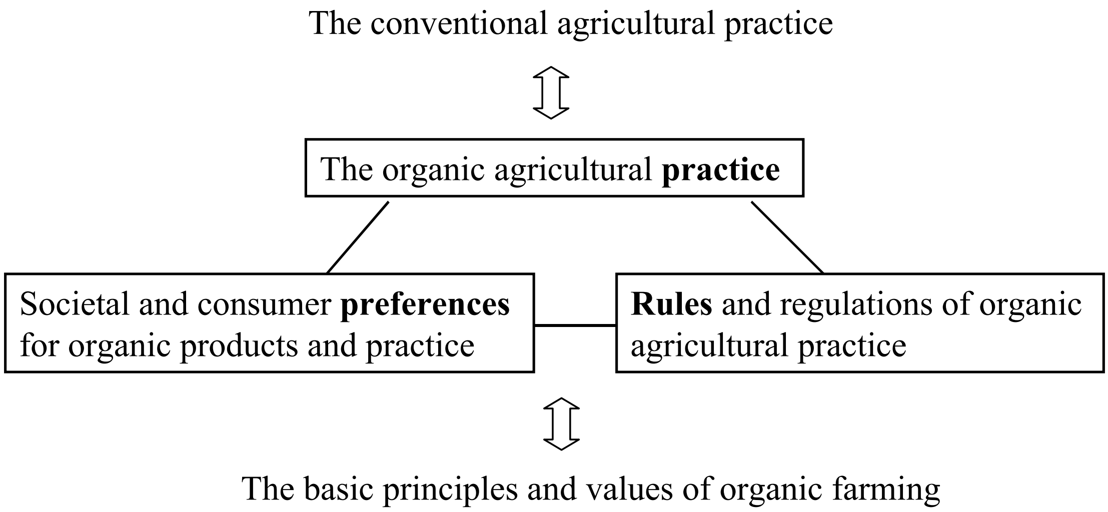

Figure 4: Three elements in the development of organic agriculture: practice, preferences, and rules – all related to the basic organic principles and values as well as to conventional agricultural practice

Originally the production of organic products was based on internal control in the movement and self-regulation by way of farmers orienting themselves towards the basic principles. But in modern organic agriculture the marketing of organic products is based on common, often governmental, certification and control procedures, which relate to the manifest rules for organic practice. Hence the organic production practice is more and more oriented towards the manifested rules, and less influenced by the farmers' interpretation of the basic values and principles in organic farming. Still, the principles and values are the common basis that correlates practice, preferences and rules. The preference for organic production may express itself in form of consumer preferences on the market or in form of political preferences that are manifested in regulations of agriculture.

Up to now, the growth of organic agriculture has been mainly based on a rise in consumer preferences for organic products, which is based on the recognition of shared values, as well as on particular rules, such as the ban on pesticides. These changes can be related to the public debate of sustainability in the wake of the World Commission report "Our common future", as well as to a more or less deliberate precautionary attitude towards the surge of new technologies in agriculture. The dominating rules, such as the ban on artificial fertilisers and pesticides, can be understood in this context. The specific interpretations of the basic principles and values in the organic movement are, however, not a matter of course. And in fact the rules have been changing continuously in connection with the development of organic farming in terms of production of new types of products and increased production area and market share.

Basically there are more restrictions on technology and use of chemical substances in organic farming in comparison with conventional agriculture and these restrictions in themselves may provide a basis for consumer preferences for organic products. But these restrictions also result in a lower production per area. Generally, the lower production results in a higher cost per unit of production, and the marketing of organic products is therefore dependent on consumer preferences or regulatory compensations.

As stated above, the changes in organic production interacts with the preferences for organic production. In terms of the implementation of an all-organic agriculture in Denmark, the evidence is that this will not take place by way of changing consumer preferences in the foreseeable future. The preferences that may bring about a total conversion to organic farming must therefore be of a political nature. However, in contrast to consumer preferences, the political regulation of agriculture is dependent upon the EC and other international institutions. As stated in section 3, The Bichel survey showed that the EC regulations in fact do prevent a compulsory conversion to organic farming in Denmark. There are, however, some possible means of expressing a political preference for organic farming in Denmark. The influence of agriculture on environment is a basis for regulation, which may motivate a political promotion of conversion, in line with the general tendency towards a shift of governmental support to agriculture from production size to environmentally friendly production methods.

4.2 Results and values

The scenario results showed that the costs of a total conversion would vary in correspondence with the primary production. This production varies with the import of feed, which in turn is dependent on the rules of organic agriculture. The costs also depend on whether the foreign consumers have preferences for organic products. Any preferences that the Danish consumers might have for organic products have not been valuated, since these preferences are irrelevant for the national economy as long as only organic products are available. All together, those benefits that have been possible to valuate are lower than the costs. However, these results are to be seen in relation to those consequences that could not be assessed, or which could not be valuated in monetary terms. The uncertainties and knowledge gaps acknowledged in the Bichel survey motivate a value inquiry that can support decisions where knowledge is lacking. And conversely, the models and results based on the knowledge that was in fact available, informs the inquiry into the values involved.

Balance and sustainability

Some of the main principles of organic farming are those of balance and sustainability. The description cited in section 2.1 speaks of a "self-sufficient and sustainable agro-ecosystem in a balanced state", which is "based as far as possible on local, renewable resources". However, there is a large export of agricultural products from Denmark today (see table 2). Hence, the idea of an all-organic Danish agriculture poses a challenge to the principles of balance and sustainability, the challenge of bringing together these principles with a large export of agricultural products.

As indicated in section 2.1, the Bichel Committee decided to work with a range of different scenarios, with the intention of extending a possibility space for a future all-organic agriculture, and not make the value-based determination of the organic scenario prematurely. The space was stretched out by means of three different presumptions on the level of import of feed to Denmark, with ensuing differences in the level of nutrients in circulation and subsequent consequences for production, environment and economy.

Having established this model space, the further modelling and calculation of scenarios illuminated other model presumptions open to discussion in light of the principles of organic farming. Some of the main aspects of balance and sustainability in the scenarios are the questions of sustaining soil fertility, the import of feed minerals, the balances in the regions exporting feed to Denmark, the question of seed and seed-carried diseases, and the question of energy balances.

Important aspects of maintaining soil fertility are maintaining organic matter, which again turns on crop management and biology activity in the soil, and keeping nutrient balances. The maintaining of organic matter is a matter of great concern and effort in the organic practice. The calculated nutrient balances revealed that the input and output of phosphorous was largely in balance, but only due to a substantial import of feed minerals to livestock. The potassium balance showed a deficit, particularly in the more sandy regions, where potassium may be leaching even from well-planned crop rotations.

These results confronted the vision of an all-organic agriculture with the questions of how the overall loss of nutrients with exported products is to be balanced, in light of the organic principles. Ideally, nutrients should be recycled from society, but this recirculation of nutrient is hardly possible within the foreseeable future, even inside the borders of Denmark. The structures of consumption and waste in society are not planned with this purpose in mind, and the available sources of nutrients in waste are more or less polluted with chemical substances.

Another question to be discussed in light of the principles of balance is the nutrient balances in the regions exporting feed to Danish organic agriculture. More nutrients are removed with crop products than with animal products, and the exporting regions would, in the long run, have to supply nutrients in order to sustain the production.

The actual modelling of the organic scenarios was based on necessary value-based presumptions, but the modelling in turn worked as an instrument for refining the value inquiry, and thus allowed for a more precise discussion of the presumptions of the modelling. This is an important aspect of the interplay of inquiry and scientific modelling shown in figure 3. In order to promote an informed discussion of the value-based presumptions, a more detailed knowledge of the values and principles involved is also needed. The focus on balance is based on a concern for sustainability. But sustainability can be understood in different ways.

Meanings of sustainability in agriculture

Gordon Douglass (1984) distinguishes between three dominant visions of agricultural sustainability: food sufficiency, stewardship and community, which are used by different groups with different views and values. Sustainability as food sufficiency looks at population growth and speaks of sustainability in terms of sufficient food production, with the necessary use of technology and resources. Agriculture is an instrument for feeding the world and economic cost-benefit analysis is the instruction, which guides application of that instrument. In this group we find the defenders of the modern "conventional", industrialised agriculture. Sustainability as stewardship is concerned with the ecological balance and the biophysical limits to agricultural production. From the ecological point of view, sustainability constrains the production and determines desirable human population levels. This is a diverse group of "environmentalists", often with a concern for the limits to growth in a finite global environment. Sustainability as community resembles the ecological point of view, but with special interest in promoting vital, coherent rural cultures. Cultural practices are taken to be as important as the products of science to sustainability, and the values of stewardship, self-reliance, humility and holism are encouraged. In this group we find the "alternative" forms of agriculture, and the modern organic farming has originated from within the community group.

Paul Thompson (1996; 1997), identifies two, and only two, philosophically distinct meanings of sustainability: resource sufficiency and functional integrity. *Resource sufficiency* matches Douglass' food sufficiency, with a focus on the foreseeable use of resources, food production and food distribution. Sustainability in this sense is an accounting approach, which entails that agriculture can fulfil the present and future generations need for food, fibre, etc. *Functional integrity* encompasses Douglass' stewardship and community meanings of sustainability. Here agriculture is viewed as a complex system of production practices, social values and ecological relations, the functional integrity of which may be nurtured or disrupted by human practice. This view of sustainability supports strategies for increasing the resilience of the system and avoidance of irreversible changes.

The two meanings of sustainability are used by Thompson in analysing different case examples, showing how resource sufficiency and functional integrity each order our priorities, when we look for signs of sustainability or its opposite.

> This means that certain kinds of values will inevitably be served in adopting one approach or the other, and in defining the system boundaries for articulating a conception of functional integrity. … It may be impossible to arrive at consensus on these value questions, but informed interdisciplinary research will be possible only when participants have a clear sense of where they stand with respect to one another.
>
> (Thompson 1996:92)

These different understandings of sustainability are connected with different values, but also with different structures of rationality and meaning. And in particular, they are connected with different conceptions of the relationship between human and nature. Resource sufficiency presumes a distinctive conception of nature, which sets man apart from nature, and where nature therefore can be seen as a "robust" nature, that is, a resource that can be substituted with other resources in economical terms. Functional integrity, on the other hand, presumes a systemic conception of nature, which sees human as an integral part of nature, and where nature therefore is seen as more or less "vulnerable", that is, as a system with critical limits (Alrøe 2000). These differences need to be taken into account when assessing the sustainability of agricultural systems – it will make a difference which meaning of sustainability is taken as point of departure (Lehman 1995; Kristensen & Halberg 1997). Research done from a resource sufficiency point of view might well be irrelevant to the questions asked from a functional integrity point of view.

From a resource sufficiency point of view the nutrient balances are not a problem, as long as there are sufficient sources of nutrients somewhere in the world. This is the accounting approach to resources. But from a functional integrity point of view, linear input-use-waste processes are not acceptable. The inputs of resources and outputs of substances does not come from and disappear into some irrelevant outer space in this perspective – the whole system needs to be taken into account. In the functional integrity view, the nurturing of self-reliant and self-reproducing systems is crucial. Hence the questions maintaining soil fertility and reproducing crops and livestock are central goals. The possibility of maintaining seed quality, especially in terms of controlling seed-carried diseases, without pesticides was one of the unanswered questions in the Bichel survey. Hence, the treatment of seed with pesticides was presumed where necessary, even though it conflicted with the present organic rules.

As shown in table 4, the use of fossil energy use, and subsequently the emission of greenhouse gases, would be lower in an all-organic agriculture. However, the agricultural production would also be lower, and furthermore some agricultural products and by-products are used for energy production in the present agriculture. This speaks for comparing energy use in form of energy balances. But a collected energy balance for agriculture is inherently problematic to establish, because energy is not an unequivocal measure. When agricultural products are used for feed or fuel, the metabolic energy is different from the fuel energy, and most products are not suitable for fuel. Furthermore the metabolic energy in feed is different for different species.

In an overall view, the primary crop production produces energy, while animal production consumes energy. In both conventional and organic agriculture the energy in grain for fuel is much larger than the use of fossil energy in the production. Organic agriculture uses less energy per unit of grain produced, while conventional agriculture produces more net energy per area due to the higher yields. The assessment of these alternative perspectives depends on the values that are taken into consideration and the conception of sustainability employed.

With regard to the emission of greenhouse gases, for instance, the importance of the system boundaries, which Thompson pointed to in the citation above, becomes evident. The production of greenhouse gases is without doubt a global question, and in the view of functional integrity the system boundaries should encompass the entire globe. However, in the international agreements the national borders are implemented as boundaries of responsibility for emissions. That is, any rise in animal production outside Denmark, as a result of a fall in the Danish production, will not enter into the Danish account of the emission of greenhouse gases.

Knowledge and precaution

The limits of knowledge and the range and unforeseeability of consequences are important questions in the functional integrity conception of sustainability, due to the view of humans as integral parts of the natural ecological systems. These questions have come into focus recently in connection with the normative concept of precaution in environmental policy. The precautionary principle is also of rising importance in agricultural policy, research and practice today.

Historically, the precautionary principle stems from the German "Vorsorgeprinzip", which was first applied in legal contexts in 1976 (Boehmer-Christiansen 1994). The literal meaning of Vorsorge combines beforehand worrying about and caring for the future. According to this principle, the responsibility towards future as well as present generations commands that the natural foundations of life are preserved and that irreversible types of damage must be avoided. The principle is put into practice by:

- early detection of dangers through comprehensive research
- acting before conclusive scientific understanding is available in front of possible irreversible damage
- and reduced discharge of pollutants and promotion of cleaner technologies.

The precautionary principle arose in the context of other important principles in German environmental policy and management, such as the "Verursacherprinzip" (polluter pays principle), which literally means that causative agent is responsible; the principle of proportionality between costs and benefits; and the principle of "Kooperation", requiring that all interested parties must be consulted and that policy should be based on consensus (Boehmer-Christiansen 1994).

The precautionary principle is evidently connected with a conception of nature as more or less vulnerable, and thus tied to sustainability as functional integrity. But it is important to note that the precautionary principle is not a primarily conservative principle in terms of maintaining status quo. Quite the contrary, underlying the precautionary principle is a commitment to change, implied by the caring about the future, and according to this principle existing production processes should be replaced with the cleanest technology available.

> Precaution above all requires a society able and willing to invest in the future, the need for which cannot be "proven" in advance, but must remain a matter of faith.
>
> (Boehmer-Christiansen 1994)

The principle was first internationally introduced in 1984 at the First International Conference on Protection of the North Sea. One of the most important expressions of the precautionary principle internationally is the Rio Declaration from the 1992 United Nations Conference on Environment and Development, also known as Agenda 21. The declaration states:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.
>
> (Tickner *et al.* 1999)

Risks and precaution in use of pesticides

It is important to distinguish between risk assessment and precaution. *Risk assessment* is concerned with the calculation of proportional risks and benefits from available scientific knowledge (e.g. Kasanmoentalib, 1996), while *the precautionary principle*, as indicated above, prescribes acting before scientific evidence is available. This distinction corresponds to the usual distinction between risk and uncertainty in economical decision theory, where risks indicate events that can be described with a probability distribution, while uncertainty indicates events where the probabilities are unknown – or where the space of possible events is undetermined.

Environmental risk assessments of pesticide use has until recently mainly been based on experimental data. But after the unforeseen discovery of pesticides in subsoil water, a large monitoring programme has been implemented in Denmark (Danish EPA 1999c). However, even the inclusion of empirical knowledge from environmental monitoring in the risk assessment of pesticides does not necessarily prevent long-term consequences like the leaching of pesticides to subsoil water, due to the long time lag between the act and the measurable consequence. This is an example of how risk assessment based on available scientific knowledge fails in avoiding unwanted consequences that are hidden due to the limits of scientific knowledge.

The pollution of sub-soil water with pesticides is often irreversible, or reversible only in a very long time horizon. And, due to the long time lag, the consequences of pesticide use that can be measured today represent past sins, which cannot be undone. Hence, even the future losses from closing down water wells, due to these past sins, cannot be avoided today. This implies that these costs cannot be included in a cost-benefit analysis of phasing out the present pesticide use – they are so-called sunk costs (Dubgaard *et al.* 1999). That is, such environmental, or systemic, consequences, which become known only after the damage is done, will not be taken into account in decisions based on economical decision theory. And in a situation of rapid technological change – such as modern agriculture, where new pesticides, for instance, are implemented in step with the removal of old pesticides due to the proof of long term systemic consequences – decisions based solely on risk assessments and economical decision theory will never prevent the continued advent of such systemic consequences.

Even though the approval procedure for pesticides today demands the investigation of far more risk factors than previously, some uncertainty will always be present in the usage of pesticides. Above all, because it is not possible to investigate all the physical and biological aspects of pesticides in nature and health due to economic and ethical concerns. Animal experiments can provide information on the risk of cancer for rats when they are exposed to certain doses of a pesticide. However, the use of this knowledge in risk assessments on the consequences agricultural use of pesticides for public health, rests on a range of presumptions that cannot be tested directly, since experimentation with humans is out of the question.

Sustainability, precaution and ethics

The principle of precautionary acting arises out of an acknowledgement of the human dependency on the environment, together with a recognition of the growing human influence on the environment and the fact that the consequences of this influence are to some degree unknown and uncontrollable. This acknowledgement motivates a shift of focus from knowledge to limits of knowledge, leading to a scientific interest in ignorance and uncertainty and towards the development of strategies for handling ignorance and acknowledged lack of knowledge (Smithson 1993, Dovers & Handmer

1995). Value inquiry and ethical reflection constitutes key elements in such a strategy, together with a systems science that recognises the importance of values and ethics.

Hans Jonas (1984) has elaborated an ethic of responsible acting, which contemplates the growth in human technological action abilities in connection with the limits of our knowledge of the consequences of our actions. In continuation of Jonas's approach, there is a need for a systemic ethics, which deals explicitly with the systemic consequences of human action (Alrøe 2000; Alrøe & Kristensen 2000). Scientific knowledge and value inquiry are mutually dependent in a systemic ethics. Factual knowledge of the systems involved is needed to address the systemic consequences of our actions; and increased knowledge of the systems of which we are a part, will in turn inflict on the goals to be pursued – sustainability being a key example. Furthermore, increased awareness of the present gaps and limits our scientific knowledge is a second order perspective on a systemic ethics, which is represented by the principle of precautionary acting.

5 Conclusion

A concrete survey to assess the radical changes of phasing out pesticides from Danish agriculture has been presented and discussed. The results of this so-called Bichel survey have been widely recognised and acclaimed. But this work also raised a range of broader methodological issues in the task of modelling an alternative and, perhaps, more sustainable agricultural system. Issues, which concerned the interplay of science and values.

Assessing the consequences of phasing out pesticides involves both an assessment of the present effects of pesticides on society and the environment, and an assessment of the consequences of changes in the agricultural system as a result of phasing out pesticides. In both cases the Bichel Committee pointed to the importance of uncertainties and lack of knowledge. Modelling the changes in the agricultural system presumes the formulation of a vision of the future state, such as for example an all-organic Danish agriculture, by way of which the necessary presumptions for the model can be determined. In turn, the model results in a scenario, which can form the basis for a critical evaluation of the presumptions in relation to the vision of the future state and the values related to the vision. Hence, an assessment like the one performed in the Bichel survey involves two major interrelated activities: the modelling process and the value inquiry.

While the modelling was based on all the available empirical knowledge, the insufficiency of this empirical basis with respect to the nature of the future state entailed that the necessary presumptions became very important for the assessment. This, in turn, motivated an inquiry into the values involved in determining the future state. Conversely, the models and results based on the knowledge that was in fact available, made the value inquiry more precise and substantiated. With regard to this, an important element in the modelling approach in the Bichel survey was the repeated consultation with a range of experts in different fields and sciences in order to critically review the presumptions and the generalisations of the available empirical knowledge in the models, and the involvement of these experts in the value inquiry.

The Bichel survey included the elaboration of different scenarios for a total conversion to organic agriculture in Denmark. The scenario results showed that, all together, those benefits that were possible to valuate were lower than the costs connected to a total conversion. However, these results are to be seen in relation to those consequences that could not be assessed, or which could not be valuated in monetary terms. The assessment was dependent on future consumer preferences for organic products and practice as well as on the valuation of the consequences of an organic conversion. Hence, the value inquiry was also important in assessing the results of the model.

The inquiry into the values involved in the vision of an all-organic Danish agriculture focused on the different perceptions of sustainability and precautionary acting in agriculture, because these concepts are intimately related in the basic ideas and principles of organic farming. The principle of precautionary acting arises out of an acknowledgement of the human dependency on the environment – which is also the basis for sustainability as functional integrity – together with a recognition of the growing human influence on the environment and the fact that the consequences of this influence are to some degree unknown and uncontrollable. Given the speed of technological innovation and change in agricultural practices, and given the time lags in the systems involved, many consequences of these changes are not well known. This acknowledgement motivates a shift of focus from knowledge to limits of knowledge, and towards the development of strategies for handling ignorance and acknowledged lack of knowledge. Value inquiry and ethical reflection constitutes key elements in such a strategy, together with a situated systems science that incorporates values and ethics.

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